Adaptation of populations to changing environments: Bioarchaeological perspectives on health for the past, present and future

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Abstract

This paper explores the contribution bioarchaeology has made, and is making, to our understanding of past health. It focuses on the importance of research on the bioarchaeology of ill health for the past, present and future, the history of its development, some research problems that have been tackled, recent developments in knowledge and analytical techniques, and finally what big questions about past health bioarchaeologists are starting to explore which are particularly relevant to today and the future. Ancient pathogen DNA analysis, stable isotope analyses, imaging histological techniques are addressed, along with answering specific questions about the impact of poor air quality, mobility, climate change and re-emerging infections. The future for

bioarchaeology is finally considered and focuses on: emphasising a question driven approach, large synthetic comparative studies of human remains in context, utilisation, and justification, of appropriate techniques of analysis, continued excavation and curation of human remains from archaeological sites, and collaborating with people form different disciplines.

Keywords

Bioarchaeology, disease, destructive techniques, contextual approach

Introduction

Bioarchaeology has had a long history of study in physical anthropology. It has seen various names attributed to it, but it essentially equates to the study of human remains from archaeological sites using a contextual approach, that is: placing the biological data from those remains into archaeological context in order to interpret those data. Bioarchaeology in North America concerns the study of human remains (e.g. see Buikstra and Beck, 2006:xvii) but in Europe it can be defined as the study of any organic remains from archaeological sites (Roberts, 2006), such as human and animal bones and plant remains. For the purposes of this paper, the North American definition will be used. The aim of this paper are to outline the study of ill health in bioarchaeology (or also termed, palaeopathology) by focusing on: the importance of research on the bioarchaeology of ill health for the past, present and future, the history of its development, some research problems that have been tackled, recent developments in knowledge and analytical techniques, and finally what big questions about past health bioarchaeologists are starting to explore which are particularly relevant to today and the future.

As Gowland & Knusel (2006: ix) state, ‘Human remains are the most tangible and direct form of evidence for understanding how people lived in the past’. Without data from human remains from archaeological sites, archaeology would be a much weaker discipline; after all, archaeology is about the study of people. Humans, like today, are central to society and, without humans, there would be no other archaeological evidence. Skeletons and preserved bodies also hold a fascination for the public, probably because they can relate ‘better to a skeleton or mummy than to a pot’ (Roberts 2009:1). This has led to many more television programmes featuring excavated human skeletons, particularly in the UK. However, bioarchaeological studies of health have developed in character from, what could be termed a ‘cottage industry’ where people who did not necessarily have the most appropriate training worked in isolation from each other, to a much more professional discipline where training is available. These studies have also moved much more away from the study of individual skeletons to a hypothesis/question driven approach to past health. In addition, there is much more of an attempt to place the biological data from human remains into context. Using multiple datasets from history, art, archaeology and ethnography to inform about diet, living conditions, work patterns, and other factors in people’s lives, it becomes possible to integrate the data to generate much more meaningful interpretations. This is considered essential. A further development is the setting of standards for skeletal data collection, starting with the North American repatriation and reburial initiated volume by Buikstra and Ubelaker (1994), followed 10 years later by the British publication (Brickley and McKinley 2004), and a more recent development by the Global History of Health Project (http://global.sbs.ohio-state.edu/). Collecting data in a standard way makes comparisons of data possible and more realistic; ultimately this is research that informs us about past health both temporally and geographically.

Exploring health and disease in bioarchaeology provides us with a window on how populations have adapted to (or not) changes in their environment. As Larsen (2008) indicates, the last 10,000 years of health changes have set the stage for what we are today, but there are biological costs to adaptation and people's responses will vary. We have moved from being extremely mobile hunters and gatherers, exploiting a wide variety of foods, including lean meat from wild animals, to domesticating plants and animals and living in permanent settlements. The contrast in living conditions is clear; practising agriculture allows populations to increase, although food variety is reduced and crops might fail, leading to dietary deficiency diseases (e.g. see Cohen 1989), and living in settled communities creates opportunities for new pathogens to flourish, including those spread to humans from their animals (e.g. see Davies et al., 2005). Alongside an Agricultural Revolution, we then saw the rise of industrialisation in the late 18^{th} and 19^{th} centuries AD.

In industrialised societies today we see many health problems that would not have been experienced by earlier pre-industrial people; these include disease related to noise, air, and water pollution, undernutrition and malnutrition, poverty, workplace hazards (although health and safety initiatives are much better today, certainly in western societies), alcohol and drug abuse. The environmental impact on health, caused by variables in people's socio-economic and political make up, can be considerable. Many health problems have increased through time, such as heart disease and, while some have declined, such as smallpox, often due to better health care provision, including improved hygiene, availability of vaccinations and antibiotic treatment, there still remain emerging diseases that were long since believed to have been eliminated, such as tuberculosis (see Davies et al 2008). 'Development' has led to eating a poorly balanced diet, and too much of it, taking less exercise, misusing antibiotics, drugs and alcohol, leading to obesity and liver problems. However, better health care is allowing us to live longer but we are developing more degenerative diseases such as cancer, our stressful work patterns cause us depression, and lung problems abound from poor air quality, some due to smoking tobacco. "Civilisation" as we know it has not brought us a 100% better life!

There have been many studies of the health of individual skeletons from archaeological sites, but more extensive population based approaches to answering specific questions have emerged in more recent years. For example, Bennike (1985) made a survey of demography and health based on several thousand skeletons through time in Denmark, and Roberts and Cox (2003) considered data on health from over 34,000 skeletons in Britain dated from prehistory to the 1850 AD, finding that health declined through time. More extensive comparative population studies have also been approached. For example, Cohen and Armelagos (1984) found a general decline in health with the transition to agriculture, and the Western Hemisphere Health Project, which considered health data from over 12,000 skeletons from the Americas and dated from before 1000BC to 1750 and beyond, also found a decline in health with time (Steckel and Rose 2002 and Figure 1). A more recent study of health with agricultural and economic intensification (20 studies), in many cases supported previous works with a notable decline in health with time (Cohen and Crane-Kramer 2007).

New methods

Probably one of the main developments in the study of past health is new methodological approaches, both invasive and non-invasive. However, while new methods can be exciting, innovative and tell us more than we could have known if we had just studied skeletons macroscopically, as Stone points out: '…the questions asked and the probability of actually getting sufficient data to answer the questions should be carefully considered before undertaking a project (that is destructive in nature, for example aDNA analysis for pathogens)' (Stone 2008:466). These new methodological approaches can be divided into: diagnosis of disease using *Ancient pathogenic DNA Analysis*, diagnosis of disease using *Histological Analysis*, analysing human remains using *Imaging* techniques such as computed tomography, for example to explore robusticity through cross sectional geometry, and the use of *Stable Isotope Analyses* to consider mobility of populations, their dietary status and impacts on their health.

Over the past 15 years there has been much research using ancient pathogen DNA analysis to diagnose diseases that only affect the soft tissues (e.g. malaria - Taylor et al 1997), to identify infection in people who died before bone changes developed (e.g.

tuberculosis, Jankauskas 1999), to diagnose disease in skeletons with non-specific bone changes (e.g. tuberculosis, Haas et al 2000), to confirm a diagnosis following macroscopic analysis (e.g. leprosy, Taylor et al 2000), and finally to identify the specific organism causing the disease (e.g. the African strain of tuberculosis, Zink et al 2004). Sequencing of the genomes of different modern pathogenic organisms has enabled pathogenic aDNA analysis to develop, but there continue to be debates about the long term survival of aDNA in different environmental circumstances (e.g. Kumar et al 2000 for tropical India), questions about methods used in different laboratories (see Cooper and Poinar 2000), and the possibility of contamination of ancient with modern DNA (Pruvost and Geigl 2004). For example, Roberts and Ingham (2008) found a worryingly high proportion of published papers on the subject of ancient pathogenic DNA analysis where independent replication of results was not done (Figure 2), a key stage of the analytical process.

Histological analysis of the microstructure of sections of bones and teeth to diagnose disease using different types of microscopy have also been more extensively used over the past 20 years (see Schultz 2001 for an overview). It has allowed more specific (pathognomonic) diagnoses of disease, for example Paget's disease (Aaron et al, 1992), sickle cell anaemia (Maat and Baig 1991), and scurvy (Brickley and Ives 2006). However, like aDNA analysis, it is a destructive technique and a real reason for doing that destructive analysis is needed. Furthermore, it has often not always been the case that direct comparisons of the histological appearance of clinically diagnosed disease in bone have been made with bone sections taken from archaeological skeletons. If this is not done then it is difficult for the untrained eye to appreciate that what is being seen is the appearance and characteristics of a specific disease.

Imaging methods, in the form of radiographic techniques of analysis have a great advantage over all the other methods under discussion here – they are non-destructive but can provide detailed information about disease. The most common radiographic method used in bioarchaeology is the "plain film radiograph" (now a "digital" radiograph that is manipulated and viewed on a computer screen). Use of plain film radiography will remain the most popular method for the foreseeable future because more sophisticated methods are more expensive; plain film radiography can identify pathological lesions that are not visible macroscopically which is what most bioarchaeologists require of the method. Focusing on computed tomography, which is seeing an increase in use in recent years in bioarchaeology, this method allows "slices" of bones and bodies to be visualised in order to diagnose disease, look at details of injuries, and assess biomechanical changes as a result of subsistence activities. For example, Rühli et al (2002) has determined whether lesions were of antemortem or post-mortem origin using CT. A more recent development has been the use of microCT (Rühli et al 2007), as illustrated by Kuhn et al's research comparing the value of mcroCT and histology in diagnosing bone disease (2007). This non-destructive technique has great potential for future diagnostic methodological options.

Analysis of specific chemical constituents in the teeth and bones (stable isotope analysis) has become, for some, very routine for skeletal analysis, certainly in some parts of the world such as North America and the UK. Strontium and oxygen isotopes are used answer questions about mobility, i.e. comparing the level of these chemicals in skeletons with levels in drinking water (oxygen) and geology and soils (strontium) known in specific areas in order to document locals and migrants (see Budd et al. 2004 for an overview). On the other hand carbon and nitrogen isotopes (the most commonly measured isotopes in archaeology) are used to answer questions about the type of diet people were eating; was it terrestrial, marine, freshwater, mainly meat etc. (see Katzenberg 2008 for an overview). Stable isotope analyses have allowed bioarchaeologists to answer fundamental questions about diet and mobility. For example, Honch et al (2006) surprisingly found a mainly terrestrial diet being eaten by people living on the Black Sea coast of Bulgaria, and Turner et al. (2007) showed an age-related difference in diet at medieval Kulubnarti in Nubia (AD550-800); children ate isotopically depleted protein and plant sources, relative to adults. In terms of mobility, Evans et al (2006) found a local and non-local group of people buried at the late Roman site of Lankhills, Winchester, Hampshire, England; the non-locals appeared to have come from several areas of Europe and eventually had been buried there. The development for stable isotope analyses that is now needed is a focus on linking evidence of disease with diet and mobility; poor diet can compromise health by leading to weaker immune systems and greater susceptibility to disease, and mobility can lead to transmission of disease to new victims and make people who move more susceptible to disease. Migration and health is a field of study that is very much part of the World Health Organisation's efforts in controlling disease, and it is well known that the frequency of tuberculosis is partly linked to migration (e.g. see Albert and Davies 2008), and the many people living in poverty today with poor diets around the world makes them more susceptible to disease.

Some key questions about past human health

As bioarchaeologists analysing human remains from archaeological sites, it is incumbent upon us to think about questions that can be answered about health in the past that may be relevant to the living today. As the motto of the Paleopathology Association says '*Mortues viventes docent*' (the dead teach the living). The World Health Organisation in 2006 published a volume on preventing disease through healthy environments. It identified outdoor and indoor air pollution, exposure to lead, poor quality water, sanitation and hygiene, climate change, and occupational factors as being the key environmental risks to health. All these factors equally apply to our ancestors' world. Some of the important questions about health that will be explored in this section have been, and are, being asked using palaeopathological data, but there are some questions that need more attention.

1. Did poor air quality affect health in the past as it does today?

Of course poor air quality can be a problem today indoors, outdoors, via specific occupations such as pottery making and textile weaving, and may also be related to specific fuels (carcinogens from burning wood, for example) and of course increased population density. In bioarchaeology, firstly identifying bone changes of respiratory disease caused by poor air quality, and second deciding what actually led to the respiratory problem, can be very challenging. However, there are two groups of substances today that might ‘pollute’ the respiratory tract: *gases*: organic (e.g. sulphur dioxide) and inorganic (e.g. tobacco smoke), and *particulates*, which may be inert substances (carbon, diesel exhaust); allergens (house dust mite, pollen), or micro-organisms (bacteria, viruses). The question is: would we expect environments to be polluted in the past? Yes, probably, because there were few legal controls until more recent times, but we might assume that people spent more time outdoors in the past, and that houses might have been better ventilated. For example, prehistoric thatched roofed structures actually allowed smoke from fires for heating and cooking to dissipate easily out of the building, whereas later in time more robust structures with tiled roofs and poorer ventilation might be expected to have poorer air quality. Naturally, too, climate and day length will affect for how long people stayed indoors. Of course, today in the developed world we are encouraged to better insulate our homes to conserve energy, have double glazed windows, and central heating – this does not create a healthy indoor environment (Jones 1999). One could also argue that in the past there was generally less pollution of the air because there were fewer “producers”, compared to more recent periods such as during industrialisation. However, we do know that our ancestors worked in a variety of occupations and many produced poor air quality, both indoors and outdoors. The air quality in the outdoor environment will also vary according to whether it is urban, rural, highland, lowland, coastal, an island or inland; all will be influenced by climate and weather, and also factors specific to those environments such as volcanic eruptions or desert sand creating particulate matter in the atmosphere.

Studying air quality using skeletal remains, it is possible to identify bone changes on surfaces of maxillary sinuses (Figure 3) and visceral surfaces of ribs, representing an inflammatory process. The aetiology of lesions on ribs is multifactorial, as illustrated in research on skeletons with known causes of death (e.g. Roberts et al 1994); tuberculosis, chronic bronchitis, pneumonia and cancer could all be responsible, as indicated in some archaeological studies (e.g. Lambert 2002). A recent comparative study of 15 skeletal samples from North America, Nubia, the Netherlands and England focused on different geographic locations, environments (urban, rural, hot, cold, wet, dry, desert, volcanic) and subsistence economies (hunting, foraging, farming) to explore air quality and its impact on sinus health (Roberts 2007 and Figure 4). Frequency rates varied considerably with female rates exceeding male at most sites. In general, urban sites had poorer air quality when compared to rural sites, with both having higher rates of sinusitis than sites representing hunter-gatherers. Dental disease may be a factor that also leads to sinusitis (upper molar diseases such as caries, abscess and periodontal disease) but, for all sites, dental disease did not appear to be a major contributory factor. Of particular interest, the people at one higher status site, post-medieval Christchurch, Spitalfields, London, had almost the lowest frequency for all sites; this may indicate that the people were protected from, what was known to be, a polluted environment in London at that time, and also that their houses had chimneys for the dissipation of smoke from fires.

2. Can evidence of infections in the past explain why some are re-emerging today and becoming drug resistant?

There are many new (e.g. Lassa fever, Creutzfeldt-Jakob disease) and re-emerging infectious diseases (drug resistant malaria, human monkeypox) today as a result of many factors. Tuberculosis is another good example of a re-emerging infection, with 1.6 million deaths in 2005 and one third of the world's population being affected (http://www.who.int/topics/tuberculosis/en/). Tuberculosis, transmitted primarily via bacteria laden droplets from lung to lung, has been around in the human population, as seen in skeletal evidence, since 6,000 BC in Italy (Canci et al 1996) – Figure 5. A disease of poverty, it increased through time, especially with urbanism and increases in population density. Early in the 20th century it started a decline, mainly due to improvements in living conditions, and it further declined with the implementation of antibiotic therapy in the 1940s and 1950s. However, from the early 1990s, it started to rise in frequency in tandem with HIV/AIDS, poverty, migration, vitamin D deficiency, crowding, poor health care, and drug resistance. We know much about TB in the past (see Roberts and Buikstra 2003 for an overview), but there is much more to be learnt, key information that could help predict the future. These data are starting to come from biomolecular analysis, or more specifically ancient DNA analysis and, as the genome of tuberculosis has now been sequenced (Cole et al 1998), and its evolutionary sequence established (Brosch et al 2002), this helps with the interpretation of ancient tuberculous DNA.

The first study of the aDNA of TB using polymerase chain reaction was in 1993 (Spigelman and Lemma 1993) and, since then the method has been applied to: confirming a diagnosis of tuberculosis based on bone changes (Faerman et al 1999), assessing the real frequency of TB, diagnosing TB where there are no bone changes (Faerman et al 1999), trying to prove non-specific lesions of TB were tuberculous (e.g. Haas et al 2000), diagnosing TB in non-human bones (e.g. Bathurst and Bart 2004), and latterly determining which organism of the *M. tb* complex was present (and specific strains) to explore evolution and change of the organism through time. For example, Taylor et al. (2007) established that four semi-nomadic pastoralist people buried at Aymyrlg in Siberia (2199-1761 BP) had TB but they were affected by *Mycobacterium bovis*, the animal form of the disease. There is currently a project funded by the UK's Natural Environmental Research Council (NERC) entitled "Biomolecular archaeology of tuberculosis in ancient Britain and Europe" (for full details of all personnel involved see http://www.dur.ac.uk/archaeology/research/projects/?mode=project&id=353**).** In this project we are studying the origin and evolution of the causative agents (strains) of TB in people in Britain and other parts of Europe. Using ancient DNA analysis of bone samples from diagnosed tuberculous skeletons from different archaeological sites and dates (prehistory to the post-medieval periods), we hope to chart appearances and changes in strains of TB through time in different parts of Europe. This will be in relation to the impact of variables related to what we know about socio-cultural, economic and political contexts at specific points in time. We are extending our research to study the relationships between the strains present in skeletons from the Old and New Worlds, both pre- and post-Columbian contact (late 15th century AD) by collaborating with Arizona

State University's, School of Human Evolution and Social Change. Our colleagues there are working on aDNA of tuberculosis in the New World. The ultimate aim is to hopefully contribute to understanding today's problem by using data on TB bacteria strain evolution and change.

3. Did people move, did they bring disease with them, and did they suffer worse health as a result of moving?

People today might move to escape danger, famine or disease, to access health care, or to get work in the hope of a better, safer and more healthy life (Roberts 2009). Long journeys can lead to larger and more significant changes in climate and culture, and people may experience poverty, poor living conditions and diet, hostility, pollution, and pressure on resources in their new homes. People may move temporarily or permanently, but the ability to move depends on economic and social status. Whether a person moves from place to place can also influence their health. Two projects, again at Durham University will illustrate why this is an interesting question and how we might tackle it in bioarchaeology. A project currently funded by the British Academy is supporting a stable strontium and oxygen isotope study of skeletons from a coastal late medieval port site in Hull, eastern England ("Hull Magistrates Court") - see http://www.dur.ac.uk/archaeology/research/projects/?mode=project&id=382. The hypothesis being tested is that sufferers from venereal syphilis (Figure 6) buried there were actually raised outside Britain and travelled there, probably through trade. Of interest is the distribution pattern of sites where skeletons with venereal syphilis are buried in that period; all were buried in cemeteries on the east coast or on major rivers linked to the North Sea. In another project, this time funded by the Arts and Humanities Research Council, the hypothesis being tested is that some of the people buried at the 7th-8th century Bamburgh Bowl-Hole Anglian Cemetery in Northumberland (north-east coastal England – Figure 7) were of non-local origin, and that locals and non-locals may have had different frequencies of disease (http://www.dur.ac.uk/archaeology/research/projects/?mode=project&id=278). Along with other skeletally derived data, integrated with archaeological and historical information, stable isotopes of strontium and oxygen are being analysed to assess origins of the people. According to the Venerable Bede's "Ecclesiastical History of the English people" (AD 673-735), the English were slaughtered and invaders came to eastern England from the continent in the 5th-6th centuries AD. Once locals and non-locals have been identified, differences in disease frequency will be explored. Understanding the impact of mobility on health is a major issue today and we need to understand the picture in the past to predict future trends.

4. Did climate change impact on past health as it is doing today?

Finally, one of the major changes that is being discussed today all around our world is climate change, and its ultimate impact on health (http://www.who.int/globalchange/climate/en/index.html). Extremes of temperature, storms, droughts, changes in weather, air pollution, water and food contamination and shortages, the presence/absence of disease vectors, and the evolution and change of micro-organisms are predicted to be the main effects of climate change for the future.

Has bioarchaeology tried to assess the relationship between climate change and health declines in the past? There appear to be very few directly focused studies, although climate history records do exist, certainly for the more recent past, and environmental archaeologists can reconstruct climate using different types of environmental evidence such as pollen, molluscs and insects. For example, in the late Medieval period in Britain the period AD1000-1300 was the warmest of the millennium (Lamb 1995) and there was increased agricultural production. However, by the mid 16th century there was the onset of the Little Ice Age until the mid 19th century, with cold wet periods and harvest failures. In another part of the world, one study, by Lukacs and Walimbe (1998), documented dental enamel hypoplastic defects in teeth of children who were buried at Inamgaon in India (1100-700 BC). A climate deterioration was noted, which affected subsistence and led to a change from nomadism to hunting and foraging, with a consequent improvement in health.

Conclusions: The future for health research in bioarchaeology

Studies of health and disease in bioarchaeology have benefited from the development of new tools of investigation. This has generated new information about past health that was not attainable before, although it has also created new problems to tackle in that development. It is now possible to answer much more complex questions about the past, questions that are relevant to living population health. However, bioarchaeologists should not forget that, before these (often destructive) methods can be used, basic age at death, sex, and metrical and non-metrical data must be collected, along with macroscopic observations of pathological lesions. Without all those data, the information generated using new methods of analysis cannot be interpreted. That is why projects such as that of the Global History of Health, based in North America is so important for collecting those basic (currently European) skeletal data in a standardised way before more sophisticated methods of analysis are used. It also allows very large scale comparative synthetic studies to be made, something that has rarely been achieved to date. Once destructive methods of analysis start being used, it is imperative that the right questions are asked of the data, and the data must then be interpreted in archaeological context. The use of destructive methods of analysis must be justified and strict methodological protocols put in place. One other key element of any bioarchaeological study of health is to involve practitioners from all relevant disciplines, whether that is clinical medicine, pathology, histology, anthropology, archaeology, chemistry, biology, biomolecular science, or the history of medicine; each has their part to play in reconstructing past patterns of health. Finally, it should be emphasised that it is vitally important to continue to both excavate human remains from archaeological sites, and also curate skeletal collections in museums and other institutions. If this is all put into place, there will be “Hope of another life” (*Spes Altera Vitae*) for the bioarchaeology of human health and disease in the future.

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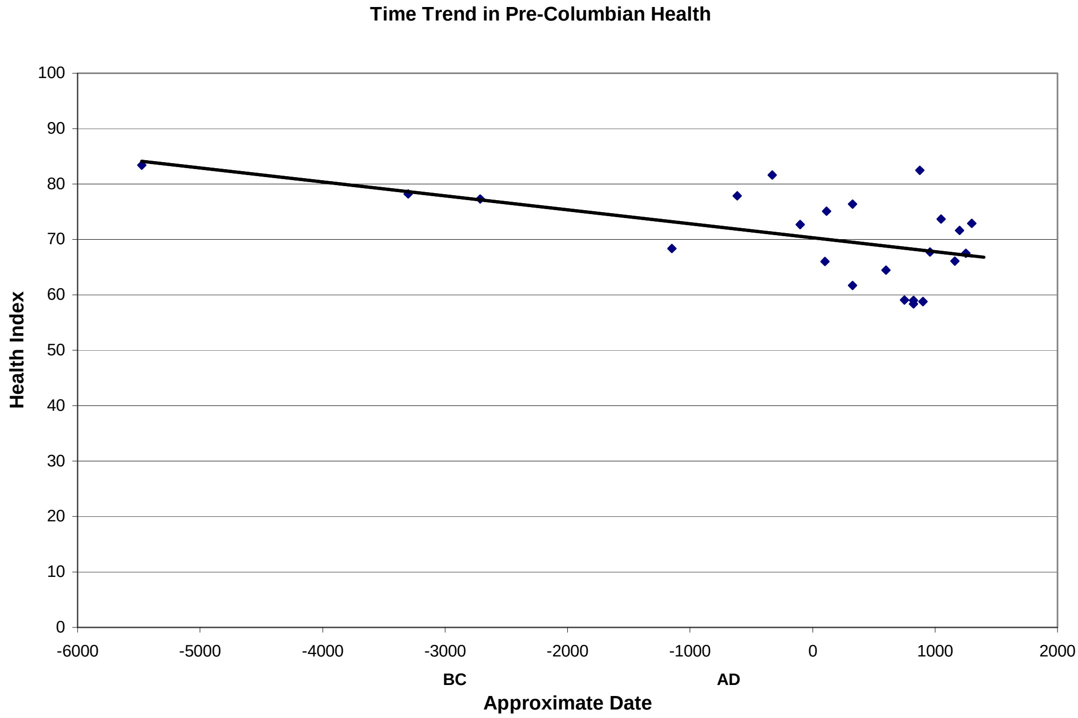
List of Figures



Time Trend in Pre-Columbian Health
Health Index
100
90
80
70
60
50
40
30
20
10
0
-6000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
BC
AD
Approximate Date

Figure 1

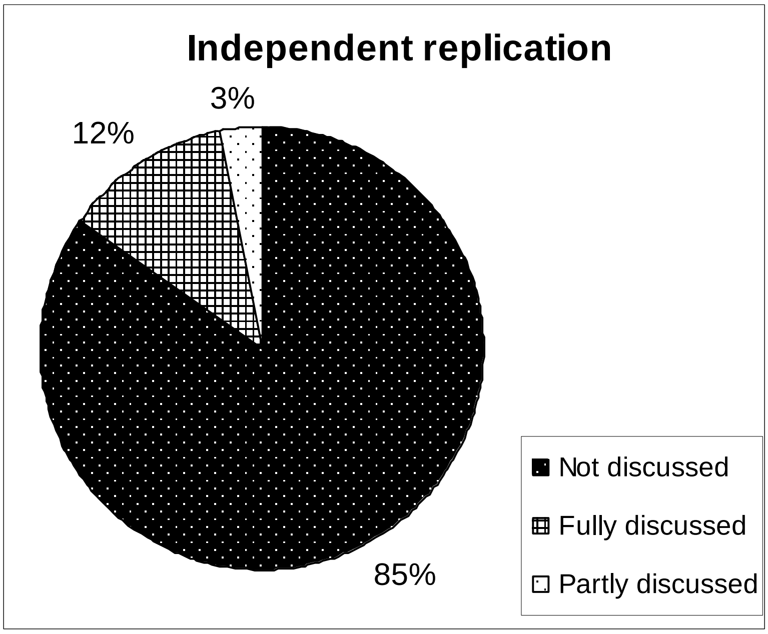

Independent replication
3%
12%
85%
Not discussed
Fully discussed
Partly discussed

Figure 2

Figure 3

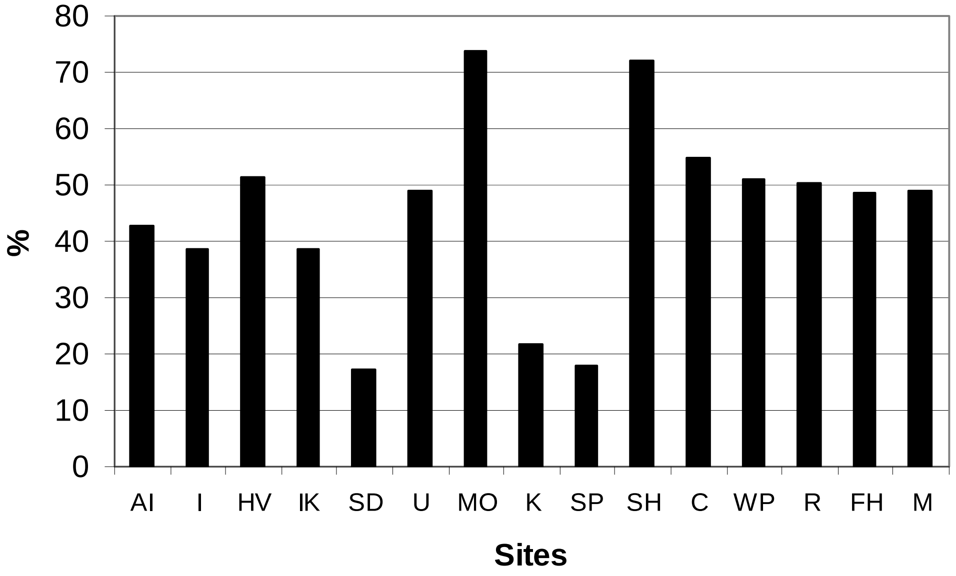


Figure 4

Key

North American sites (USA)

AI Aeutian Islands
I Illinois sample
HV Hardin Village, Kentucky
IK Indian Knoll, Kentucky
SD South Dakota sample

North America (Canada)

U Uxbridge
MO Moatfield

The Netherlands

M Maastricht

Nubia

Kulubnarti

England

SP Christchurch, Spitalfields, London
SH St Helen-on-the-Walls, York
C St James and St Mary Magdalene, Chichester, Sussex
WP Wharram Percy, North Yorkshire
R Raunds Furnells, Northamptonshire
FH Fishergate House, York

Figure 5

Figure 6

Figure 7